

MODELLING AND SIMULATION OF A PHOTOVOLTAIC SYSTEM WITH MPPT CONTROLLER

*A thesis submitted in partial fulfilment of the requirements for the degree of
Bachelors of Technology in “Electrical Engineering”
By*

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**Department of Electrical Engineering,
National Institute of Technology, Rourkela**

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Under the Supervision of

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**NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA**

CERTIFICATE

This is to certify that the thesis entitled “**MODELLING AND SIMULATION OF A PHOTOVOLTAIC SYSTEM WITH MPPT CONTROLLER**” submitted by RAJEEV RANJAN (110EE0411) in partial fulfilment of the requirements for the award of Bachelor of Technology degree in Electrical Engineering at National Institute of Technology, Rourkela is an authentic work carried out by them under my supervision and guidance. To the best of my knowledge the content of this thesis has not been submitted to any other university/Institute for the award of any Degree.

DATE:13-05-2016

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DEDICATED TO

Our beloved family, friends & the
almighty

ABSTRACT

Solar energy has become one of the most popular renewable energies due to the drastic increase of global energy demand and rapid depletion of conventional fossil fuel resources. Advanced power electronic systems are required to utilize and develop renewable energy sources. In solar system, utilizing of maximum power from the source is one of the most important functions of the power electronic converters. The output power characteristics of a PV array are influenced by the environmental factors so that the conversion efficiency is low. Therefore a maximum power tracking (MPPT) technique is necessary to track the peak power to maximize the efficiency.

This project focuses on mathematical piece wise linear modelling and simulation of three diode model of a PV solar cell. The shunt and series resistance is calculated by using Newton Raphson iterative method by varying solar irradiance and temperature. The MPPT algorithm is implemented by using buck converter in MATLAB/SIMULINK.

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ABBREVIATIONS AND ACRONYMS

PV	Photovoltaic
DC	Direct Current
MPPT	Maximum Power Point Tracking
P&O	Perturb and Observe
STP	Standard temperature and pressure
N-R	Newton Raphson

CHAPTER – 1

1.1. INTRODUCTION

Over the past decade, solar energy source has shown the potential by robust and continuous growth. In universal, P-V or I-V curve have distinct point called Maximum power point, Where With maximum efficiency the total P-V system is been operated and gives its maximum power output. For this, Maximum Power Point Tracker (MPPT) algorithm is used to extract the maximum available power at every operating point. Various MPPT algorithms are available in literature such as Perturb and observe (P & O), Hill climb search (HCS), Advanced P & O, Fuzzy logic, neural network algorithms etc. MPPT techniques are implemented by using different types of power electronics converter like buck converters, boost converters, SEPIC converter, and buck converter etc. Due to the PV system being quite expensive, optimization of the system performance are widely used by predictive performance tools. Under the Optimized Test Conditions (OTCs), PV manufacturers are providing limited tabular data which points to a cell of 25°C at 1000 W/m² and at 1.5 air mass spectral distributions. But PV cells work under standards very far from the OTCs. Research needs failed due to this reason, when the data in the datasheet shown. Usually, A physical image which express PV current with the environmental parameters and most basic technical features depending on this there are analytical equations, such as the operating voltage, the surrounding temperature, and the irradiance. By mathematical formulae Analytical ways are common methods in estimating the parameters. Furthermore, analytical methods use the curve characteristics or semiconductor variables which are absent in the datasheet. Recently, PV parameter prediction and analysis is considered as a multidimensional parametric problem. Several solving ways, such as Newton Raphson iterative technique, Genetic Algorithms (GA), Chaos Particle Swarm Optimization (CPSO), Firefly, and Pattern Search (PS) were issued. These algorithms bring out the appropriate parameters by reducing the Root Mean Square Error (RMSE) as the fundamental relation in the optimization system.

1.2. MOTIVATION

It is clear that the world energy demands cannot be make my conventional source .Taking into account the growing population it is very important to find as sustainable source of power. In this regard renewable energy presents unique potential. Solar power is an important of the renewable energy mix in the world today but several factor have limited its widespread use and adoption.

One of the major issue is the relatively costlier installation of PV array .That has rendered it uncompetitive in the energy market. So need of the ours is more research into making solar cheaper. Modelling and simulation of PV arrays is done to estimate its characteristics better and extract maximum power possible .The I-V and P-V characteristics of a PV array for varying atmospheric condition enable as to make better design interfacing of a synchronous buck converter with PV array acts as impedance matching device and make it possible to get optimum power from it

1.3 OBJECTIVE

- Development of a piece wise linear model for PV module consisting three diodes connected in parallel with voltage controlled resistance for high performance.
- Estimation of the series resistance and shunt resistance by Newton Raphson iteration technique for matching of power and I-V characteristics for the variation of temperature and irradiation.
- Development of MPPT controller by using buck converter.

1.4.LITERATURE SURVEY

The researches on “Solar Energy Systems” is going on since a long time all around the world by many researchers and engineers. To improve the efficiency and control the output of solar cell within economic cost, advanced control mechanism are required as it comes with low efficiency. This modern advanced control mechanism based on power electronics is known as “Maximum Power Point Tracking (MPPT)”.

A PV cell operation is analysed at various solar radiation intensity and temperature over a day [1]. The current vs voltage and power vs voltage characteristics is obtained by mathematical modelling and MATLAB simulation of PV system [2].

The cause of variation in the temperature and solar radiation in PV cell’s characteristics curve and effect of partial shading over PV cell are assessed by an accurate analytical modelling of a two diode PV cell [3].

Various PV cells are simulated and compared with the manufacturing datasheet for error analysis [4]. By using MATLAB/Simulink, generalised modelling of PV cell is obtained and partial shading effect over different MPPT techniques is used to obtain optimum power of system and algorithm

is studied for optimised system [5]. For partial shading variation of peak points in power vs voltage characteristics is shown [6].

For different temperature from STP is discussed for mathematical and theoretical analysis of a PV cell [7]. At various solar radiation intensity, a relative analysis of different maximum power point tracking (MPPT) is done to make the output power nearly constant in each cases

1.5 .ORGANIZATION OF THE THESIS

This thesis is organized as follows:

Chapter 1:

This chapter introduce the necessity and increasing demand of PV power generation and advantage of PV power generation over traditional power generation as well as objectives and motivation.

Chapter 2:

In this chapter PV cell modelling is done with three different models: Classical model, R_{sh} model and piecewise linear model.

Chapter 3

In this chapter MPPT controller with buck converter is discussed

Chapter 4

In this chapter simulation of buck converter circuit in conjunction with the PV cell and MPPT controller is included.

Chapter 5

In this chapter conclusion of thesis along with its scope in future is included.

CHAPTER – 2

Modelling of PV cell

2.1. Introduction to Photovoltaic system

A PV cell is the smallest block of PV system. Since a PV cell can generate very small current (nearly 30mA) and voltage (0.6V), a PV module is designed with series and parallel connection of PV cells to increase voltage and current respectively and panel contains large numbers of array of such a combination. The solar energy is converted to electrical energy in PV panel having semiconductor materials. When solar energy is more than critical energy semiconductor, photo current is generated due to photo effect. Electrons are emitted and connected with load constitutes electric current.

Materials used for PV Cell

Thin layer of silicon is used on most of the solar cell which forms an electric field when sun light strikes on the cell. Types of silicon used in PV cell are-

1. Single crystalline semiconductor.
2. Crystalline semiconductor.

In recent day advanced semiconductor materials are used for PV cells are

1. Metallic element compound (GaAs).
2. Cd chemical compound (CdTe).
3. Copper atomic number 49 Diselenide (CuInSe_2).

2.2. MODELLING OF PV CELL

A current proportional to solar radiation is produced when PV cell exposed to sun light. An ideal solar cell is possible in a circuit as a current source parallel connected to diode. Generally PV cells are non-ideal, a shunt and series resistance are connected for accurate modelling as shown in figure 2.1. The existing model (classical model and R_{sh} and R_s) with proposed model is designed in MATLAB/Simulink in this project.

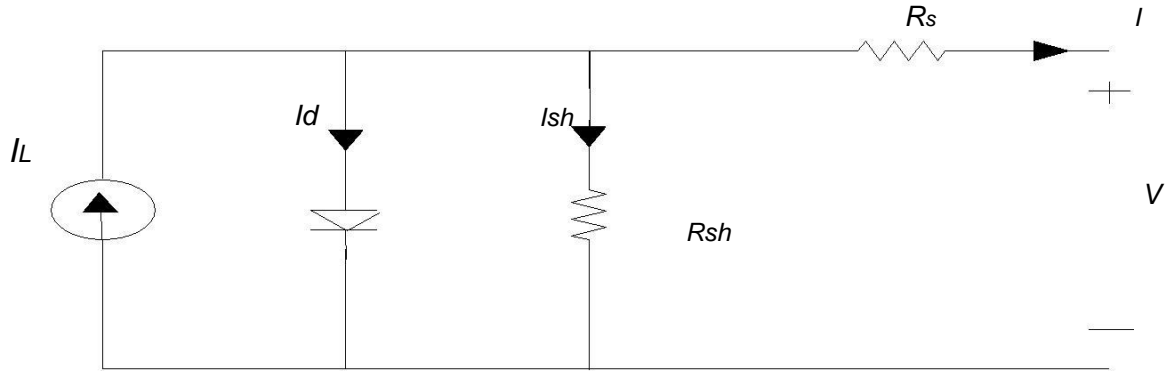


Fig. 2.1 Classical model of single PV cell

The mathematical equation for this model can be given as

$$I = I_L - I_d - \left(\frac{V + IR_s}{R_{sh}} \right) \quad 2.1.1$$

$$I_d = I_0 \left[e^{\frac{qV}{AkT}} - 1 \right] \quad 2.1.2$$

Where

I_L - light emitted photo current

I_d - current through diode

I_0 - reverse saturation current of the diode

V - Diode voltage (V)

T - Temperature (K)

k - 1.380658×10^{-23} (Boltzmann constant [J/K])

q - 1.6×10^{-19} Charge of electron

A - Diode ideality factor

2.3. R_{sh} Model

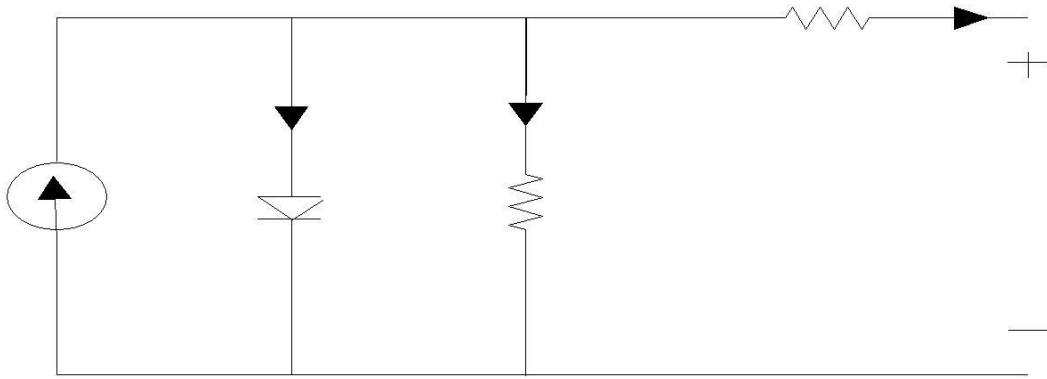


Fig. 2.2 R_{sh} Model of PV cell

Similar method to find load current and diode current as in classical model but determined by the Newton Raphson method.

$$R_{sh} = \frac{V_{MAX} (V_{MAX} + I_{MAX} R_{SH})}{[V_{MAX} (I_P - I_D) - P_{MAX}]} \quad (2.3.1)$$

With the initial condition

$$R_{SH} = \left(\frac{V_{MAX}}{I_{SC} - I_{MAX}} \right) - \left(\frac{V_{OC} - V_{MAX}}{I_{MAX}} \right) \quad (2.3.2)$$

$$\text{And } R_s = 0 \quad (2.3.3)$$

Where

V_{max} - Voltage at maximum power

I_{SC} - Short circuit current

V_{OC} - Open circuit voltage

I_{max} = Current at maximum power

The advantages of R_{sh} and R_s model over classical model is matching of R_{sh} and R_s for maximum Power output by iterative method. Hence for high accurate modelling, using datasheet information those parameters can be calculated which is open circuit voltage, maximum power and short circuit current. Newton-Raphson method is used for computing these parameters and computed, by equation (2.3.1). Newton-Raphson method has the good and a quick convergence with an initial values near the root, as given in equation (2.3.2). So, within a few iteration a better solution of R_{sh} function of R_s by equation (2.3.1) is obtained until the optimum experimental power and voltage values (P_{max}, V_{max}) matching with datasheet values of different module.

2.4. Proposed PV Modelling

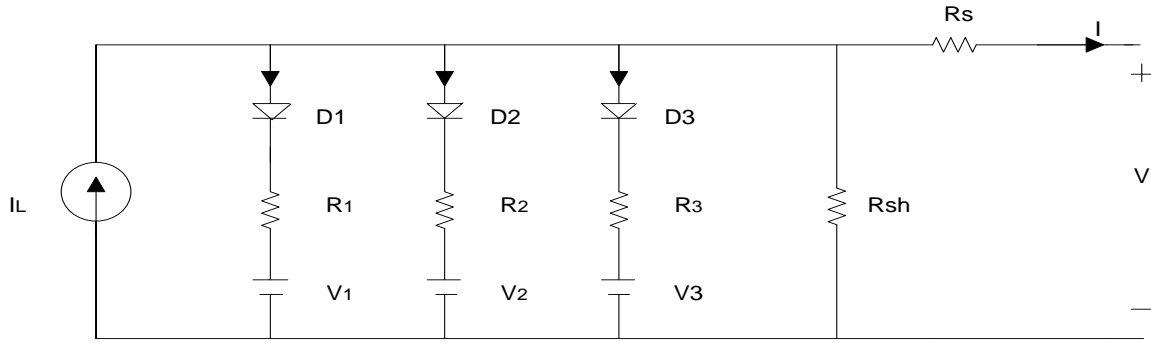


Fig.2.3. Proposed Piece Wise Linear Model

So for the above circuit the mathematical model is

$$I = I_L - I_{d1} - I_{d2} - I_{d3} - \left(\frac{V + IR_s}{R_{sh}} \right) \quad (2.4.1)$$

Where

I_{d1} - current through diode1

I_{d2} - current through diode2

I_{d3} - current through diode 3

To control the power (constant power) voltage controlled resistor in series with diodes is used near the maximum power point voltage (V_{max}) although there is little change in voltage near the V_{max} (between $0.9V_{max}$ to $1.1V_{max}$ with $0.1V_{max}$ interval) by suitable switching ON and OFF of the diodes connected in parallel rather than switching of all the diodes at the same time.

The detailed analysis of switching ON and OFF of the diodes connected in parallel and determination of the value of the voltage controlled register are given below. The switching voltages are taken at $V_1 = 0.9V_{\max}$, $V_2 = V_{\max}$, $V_3 = 1.1V_{\max}$.

Interval 1: ($V_D < V_1$)

($V_1 = 0.9 V_{\max}$). When the generated voltage from the PV panel is less than V_1 , then all the diodes are in OFF state, and there will be no flow of current through those diodes, So all the light generated current from the PV panel will flow through the load and a very small portion of the I_L will pass through the shunt resistance R_{sh} , that's why the current is almost remains constant in this interval

Interval 2: ($V_1 < V_D < V_2$)

In this case diode D_1 will be ON and the value of PV current falls from I_L to $I_L - I_{D1}$

R_1 is given in the following equation (2.4.2):

$$R_1 = \frac{V_{MAX} - 0.9V_{MAX}}{I_{D1}} \quad (2.4.2)$$

Interval 3: ($V_2 < V_D < V_3$)

Diodes D_1 and D_2 are ON.

The current passing through diode D_1 is given by the equation (2.4.3):

$$I_{D1} = \frac{1.1V_{MAX} - 0.9V_{MAX}}{R_1} \quad (2.4.3)$$

The current passing through the diode D_2 becomes:

$$I_{D2} = I_D - I_{D1} - I \quad (2.4.4)$$

R_2 Computed as follows

$$R_2 = \frac{1.1V_{MAX} - V_{MAX}}{I_{D2}} \quad (2.4.5)$$

Interval 4: ($V_3 < V_D < V_{OC}$)

In this case all the three diodes will be turned ON and the current passing through the load will be zero at V_{oc} . The current passing through the diode D_1 is given in the equation (2.4.6)

$$I_{D1} = \frac{V_{OC} - 1.1V_{MAX}}{R_1} \quad (2.4.6)$$

Similarly the current passing through the diode D_2 is given as:

$$I_{D2} = \frac{V_{OC} - 1.1V_{MAX}}{R_2} \quad (2.4.7)$$

In the same way current passing diode D_3 is given by:

$$I_{D3} = I_L - I_{D1} - I_{D2} - I \quad (2.4.8)$$

In this proposed model R_{sh} and R_s are calculated by Newton – Raphson iteration method same to the procedure proposed given in equation [2.3-1, 2, 3].

2.5 SIMULATION RESULT

The Classical model, R_{sh} model, proposed piece wise linear model are designed in MATLAB/Simulink for different model and their comparative study is given below.

2.5.1. At different temperatures

Current vs Voltage (I-V) and Power vs Voltage (P-V) characteristics are shown in Fig 2.4 and Fig 2.5 for various models at temperature 25°C and 50°C and the variation is observed.

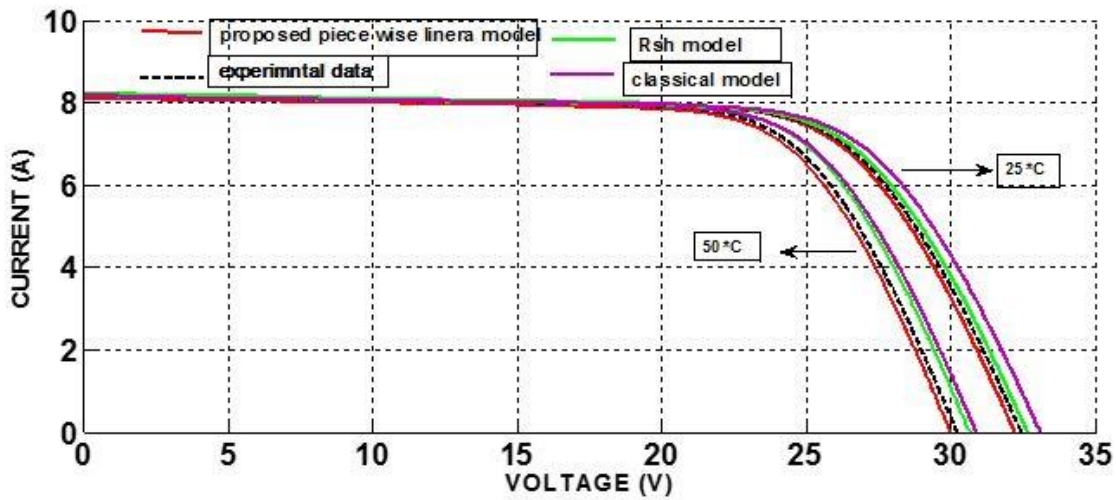


Fig 2.4 Current-Voltage characteristics of PV module at different temperature

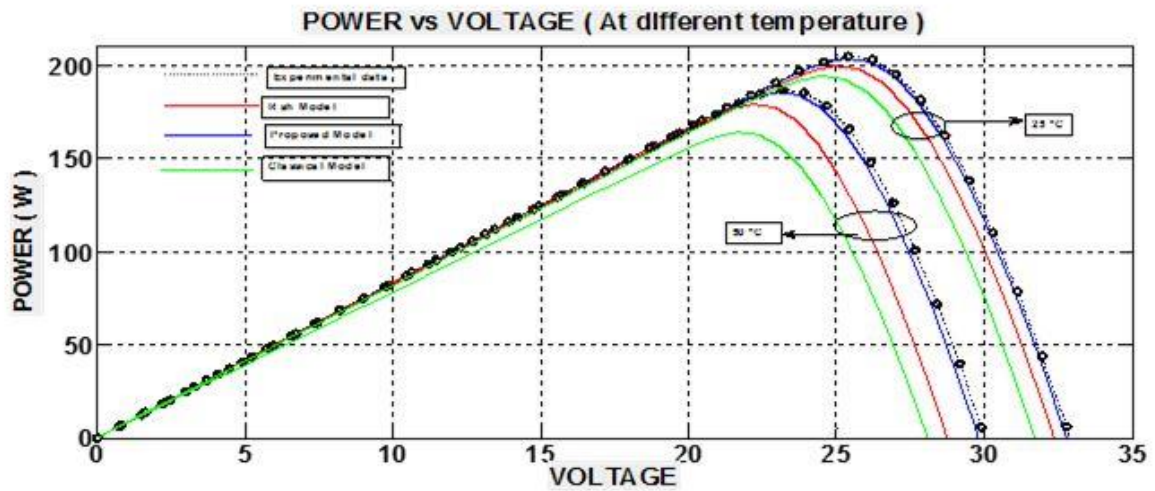


Fig. 2.5 Power-Voltage characteristics of PV module at different temperature

From the on top of I-V and P-V characteristics of various models (classical, Rsh and planned model) at completely different temperature, the planned model has its characteristics a great deal near the plot obtained from the producing datasheet

2.5.2 At different irradiation

I-V and P-V characteristics area unit shown in Fig two.6 and Fig two.7 for numerous models at irradiation 800W/m² and 1000W/m² and also the variation is discovered. The legends utilized in higher than figure is additionally

Applicable here

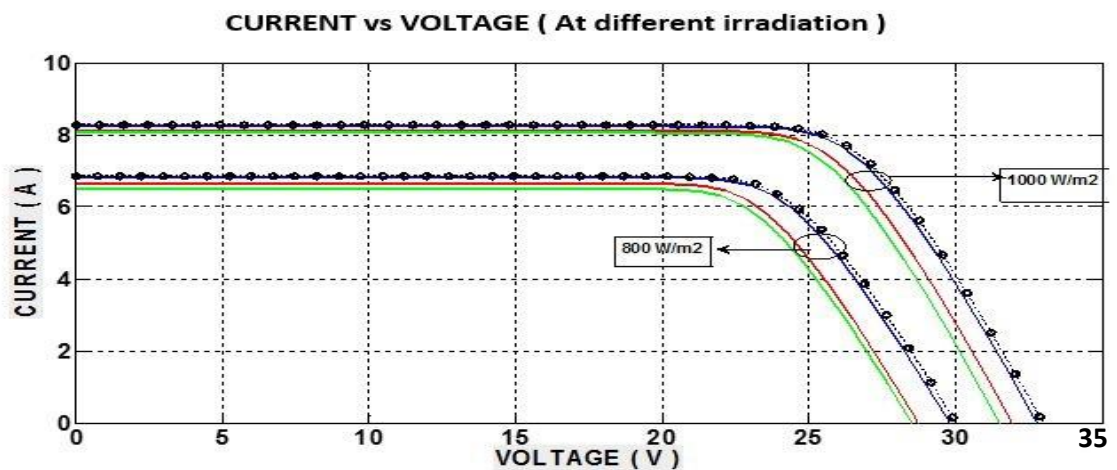


Fig. 2.6 Current vs Voltage Characteristics of PV module at different irradiation

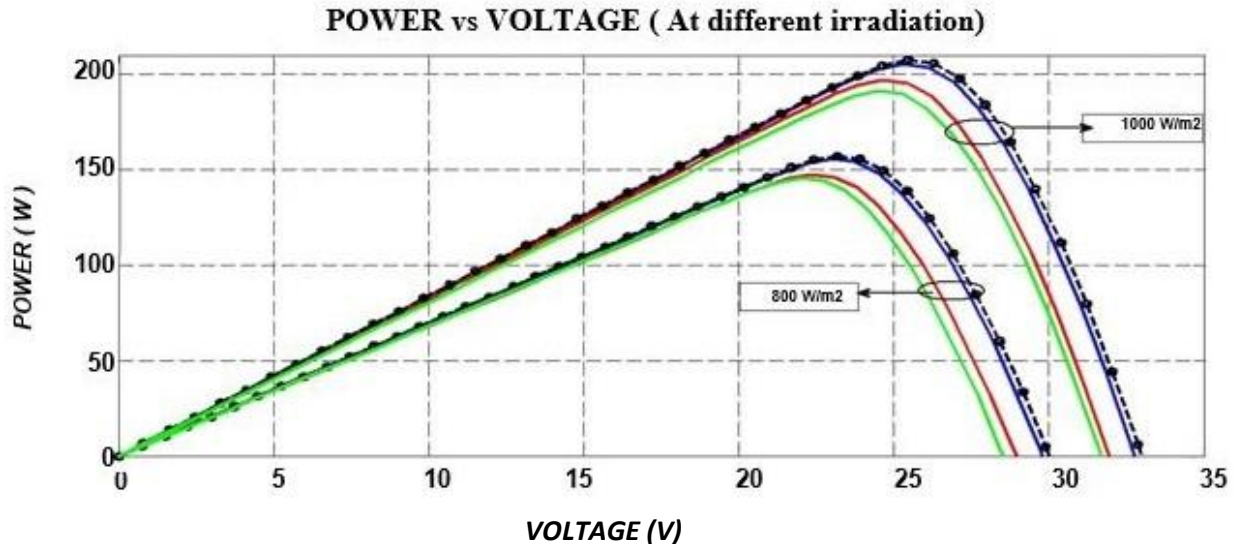


Fig. 2.7 Power vs Voltage Characteristics of PV module at different irradiation

From the higher than i-v and p-v characteristics of various models (classical, Rsh and planned model) at totally different irradiation, the planned model has its characteristics a great deal near the plot obtained from the producing datasheet.

- At low temperature the classical model gives desired values but significant error is introduced as temperature and insolation increases.
- The shunt resistance model gives higher results compared to classical model as approximation is finished by Newton Raphson methodology but it's conjointly not satisfactory for higher temperature and insolation amount.
- The three diode model gives economical results with significant accuracy overcoming the restrictions of 1st and 2nd models.
- With increase in insolation the current, voltage and corresponding power output will increase.
- As temperature will increase current will increase to a small degree however voltage decreases considerably leading to decrease in power output.

2.5.3 Relative error in power w.r.t. temperature

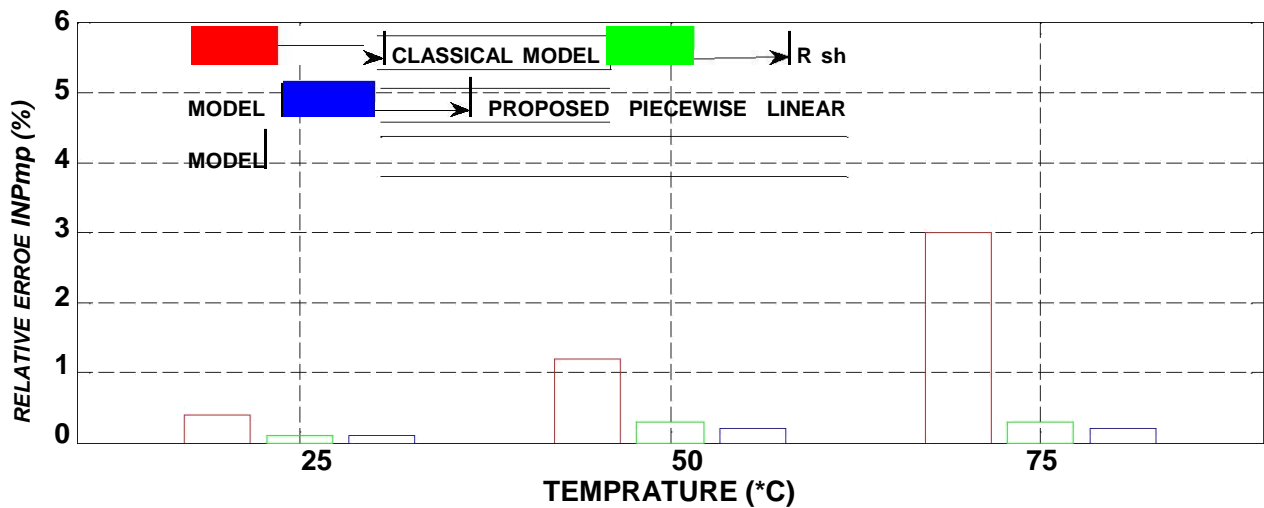


Fig. 2.8 Relative error in power w.r.t. temperature

The relative error in power output of three models with respect to temperature area unit aforethought in Figure 2.8 and it's determined that the planned three diode model shows less deviation from datasheet values at higher values of temperature

2.5.4. Relative error in V_{oc} w.r.t. temperature

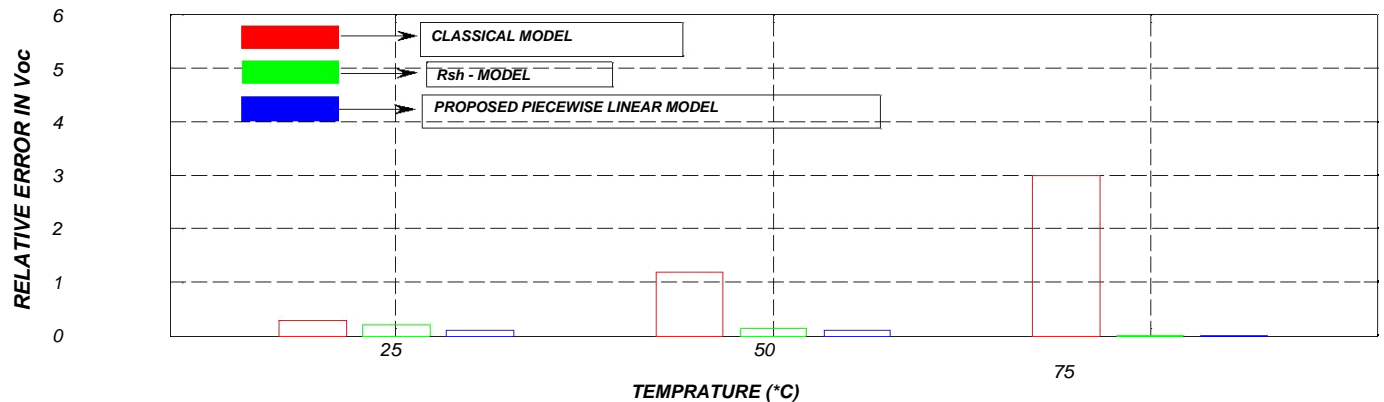


Fig. 2.9 Relative error in V_{oc} w.r.t. temperature

CHAPTER 3

3.1 Introduction to Maximum Power Point Tracking

The maximum power is extracted for the optimal utilisation of panel as installation cost of PV panel is high. Over the period of a day, temperature and solar isolation changes. So, main moto is to obtain voltage that corresponds to maximum power output for the different radiation intensity and temperature. Solar panel without optimised technique leads to wastages of solar energy. The variation in solar radiation limits the optimum utilisation of solar panel which can be overcome by Maximum Power Point Tracking (MPPT) technique to obtain optimum power from the panel at every instant of time. The aim of MPPT technique is to get operating voltage of panel corresponding to maximum power at the load. MPPT is an electronic circuit with an ability to track voltage (VMPP) or current (IMPP) periodically to get optimal power from PV panel at all environmental conditions.

Some required characteristics of MPPT techniques are:

- Cheaper
- Easy to implement and to install.
- Rapid tracking response for the dynamic analysis and tracking.
- Ability to track the MPP for varying solar radiation and temperature over wide range.

3.2 Types of MPPT Technique

Among several MPPT techniques for obtaining optimal power, they can be classified base on complexity, efficiency and cost. Some of the techniques are listed below:

- i. Perturb and Observe (P &O)
- ii. Incremental conductance
- iii. Fractional open circuit voltage
- iv. Fractional short circuit current
- v. Current sweep

Perturb and observe (P & O) algorithm is used for simplicity.

3.3 Perturb and Observe Algorithm

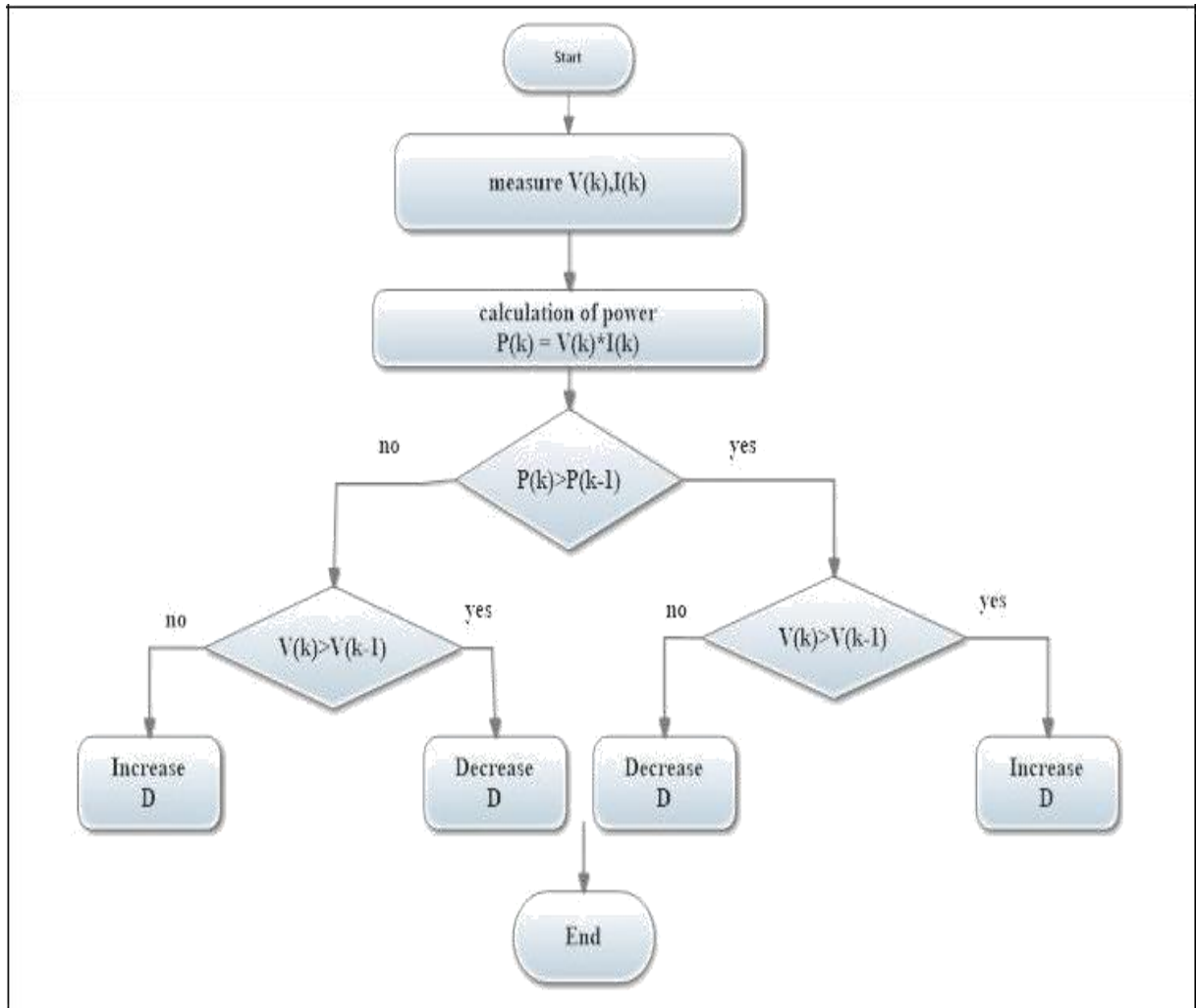


Fig. 3.1 P&O Flowchart

Table 3.1 Result of Different Models at 25°C and 1000 W/m²

<i>Parameters</i>	<i>PWL Model</i>	<i>Rsh Model</i>	<i>Classical Model</i>	<i>Manufacturer datasheet value</i>
P_{max} (W)	200.01	198.14	196.340	200.143
V_{max} (V)	26.28	26.27	26.24	26.3
I_{max} (A)	7.58	7.54	7.52	7.61
R_{sh} (Ω)	414.89	414.8	415.40	--
R_s (Ω)	0.245	0.245	0.221	--
R_1, R_2, R_3 (Ω)	7.12 ,3.13, 2.345	--	--	--

Table 3.2 Manufacturer datasheet values

Maximum Power (P_{max})	200.143W
Voltage at maximum Power (V_{max})	26.3V
Current at max Power (I_{max})	7.61A
Short circuit Current (I_{sc})	8.21A
Open circuit Voltage (V_{oc})	32.9V
Light emitted Current (I_L)	8.23A

CHAPTER 4

DESIGN OF BUCK CONVERTER

The basic operation of the buck converter with an inductance is controlled by two switches (Usually a semiconductor device and a diode). With controlled switching of converter, output power can be controlled for desired value. It is assumed that input and output voltage remains constant over the cycle.

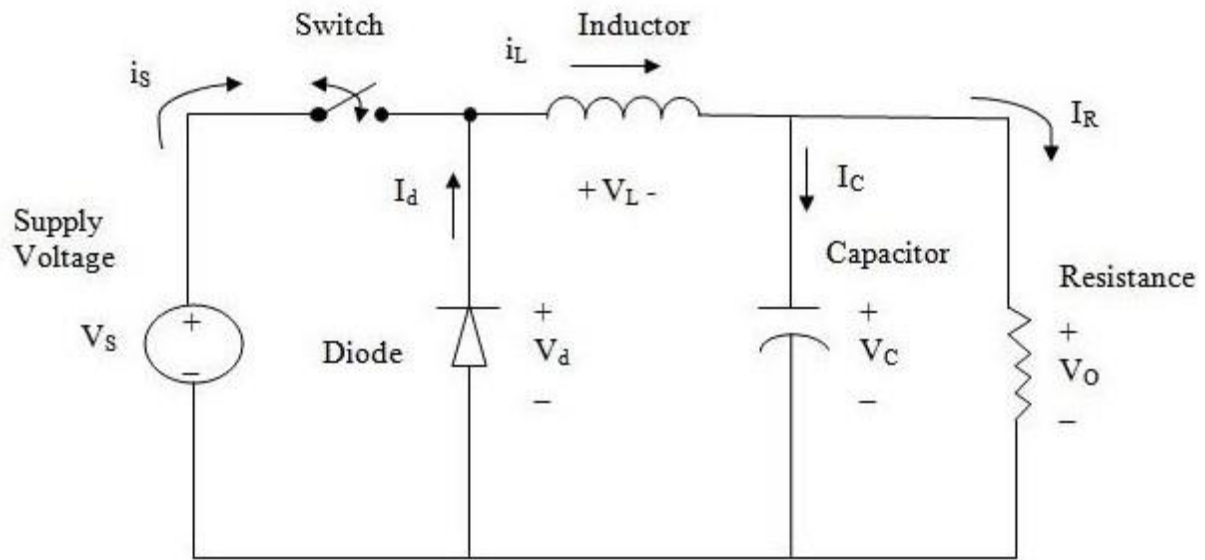


Figure 4.1 Buck converter

When switch is on, supply charges the inductor which stores energy magnetic field. No current flows through the diode as it is reverse biased and gets open circuited. At the same time capacitor gets discharged to maintain the load voltage. An exponential current flows through the inductor. This operation is called ON-mode.

When switch is turned off, inductor act as voltage source which supplies power to the load and diode turns on. . The voltage across the output will be the summation of input voltage and the voltage across the inductor. Thus stepped up voltage is obtained across the load. Capacitor maintains the constant voltage across the load. This operation is called OFF-Mode operation. In this way output power control is achieved.

.4.1. MPPT controller

To obtain the optimistic power by interlinked PV or solar powered system from transmission line which is indeed optimised system, MPPT methods are used in grids linked with inverters, battery chargers powered by solar power system and other same type of device. At no-load, relationship between PV voltage and other parameter like radiation, resistance and temperature is too much complex. Hence dependent efficiency on P-V and I-V characteristics is non- linear. To resolve this problem an appropriate load is connected at output side so that desirable power output can be obtained at any condition with changing solar radiation and temperature. The MPPT device is incorporated with the converter to convert electric power and supplies converted voltage or current, regulates and filters for operation of loads such as motors, batteries or power grids.

Out of many MPPT methods and techniques used in PV system one method is discussed here:

4.2. FRACTIONAL OPEN CIRCUIT (FOC) VOLTAGE ALGORITHM

The main concept of the algorithm is that PV voltage at Maximum Power Point is directly proportional to the open circuit voltage V_{oc} . The constant of proportionality depends on the manufacturing of the cell like solar cell technology, fill factor and climate conditions.

$$K_1 = V_{mpp} * V_{oc}$$

The constant, K_1 varies in between 0.71 and 0.78. The constant k depends on the sort and configuration of the electrical phenomenon panel. The circuit voltage should be measured and therefore the MPP determined in how for different close conditions. Usually, the system disconnects the load sporadically to live FOC and calculate the in operation voltage. This methodology has some clear disadvantages, temporary power loss is obvious. An alternate

Methodology would be to use one or a lot of watching cells, however they additionally ought

To be chosen and placed terribly rigorously to mirror truth open circuit voltage of the system.

Although this methodology is kind of easy and sturdy and does not need a microcontroller, the constant solely allows a crude approximation of the MPP. Other algorithms can considerably increase the highest power drawn from a similar PV installation

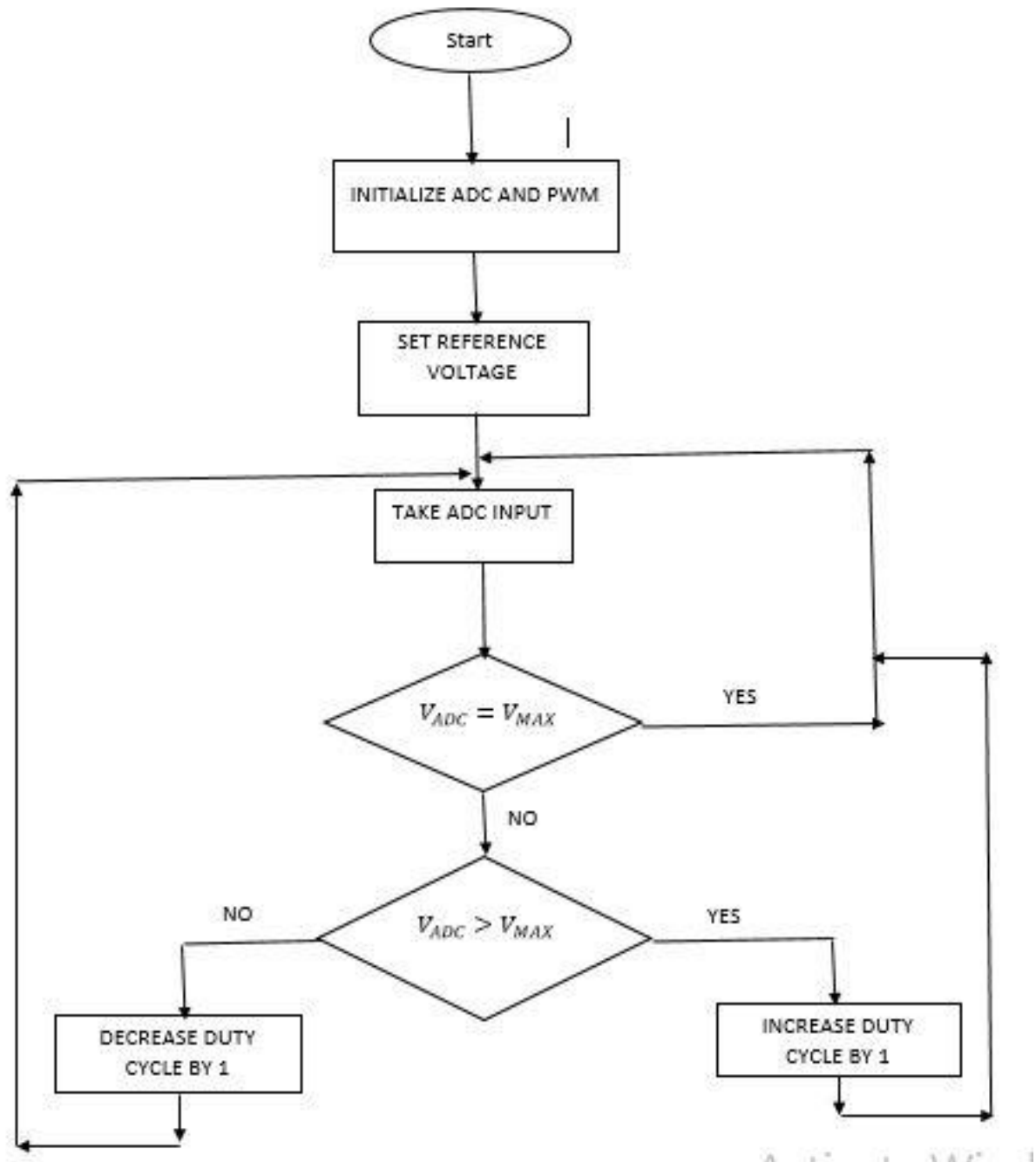


Fig-4.2 fractional open circuit voltage algorithm flowchart

4.3 design parameters:

$$V_{in} = 32.9$$

$$V_{out} = 26.3$$

$$I_{load} = 7.61A$$

$$F_{sw} = 200kHz$$

$$K = \frac{V_{out}}{V_{in}} = 0.8$$

$$I_{ripple} = 2.283$$

(a) Inductance Calculation:

In DC-DC converter Inductor and Capacitor act as filter to filter out higher order harmonics. Hence Inductance removes the ripples from the output current.

For an inductor,

$$L = (V_{in} - V_{out}) * \left(\frac{D}{F_{sw} * I_{ripple}} \right) \quad (4.3.1)$$

$$L = 11.56 \mu H$$

(b) Output Capacitor Calculation:

The output capacitor voltage is resultant sum of effective series resistance ripple voltage, load current sag voltage supplied by capacitor as the inductor is discharged and capacitor's effective series inductance ripple voltage. As ESL is not rated on capacitor, so let's assume $ESL = 0$. But with increase in switching frequency, ESL value is taken under consideration.

$$C_{out} = \left(\frac{\Delta I * \Delta T}{\Delta V - \Delta I * ESR} \right) \quad (4.3.2)$$

$$C_{out} = 321.5 \mu F$$

This equation shows that it depends on ESR, C and ESL. With suitable approximation, we can remove the other parameter from the equation and depends only on ESR which can be controlled. ESR is taken from rating of amps rated capacitors.

(c) Input Capacitor

For critical condition of duty cycle, $D = 80\%$ and under this condition buck converter's ripple input current is half of the output load current. Input capacitor is selected based on ESR to meet desired ripple voltage. Output ripple voltage is required more stringent compared to input. Here, the maximum input voltage ripple was defined as 200 millivolts. For input capacitor, ripple current rating is the important factor. Many times input ripple is more than output.

$$C_{in} = \left(\frac{\delta I}{\frac{V_{ripple}}{I_{ripple}} - ESR} \right) \quad (4.3.3)$$

$$C_{in} = 511 \mu F$$

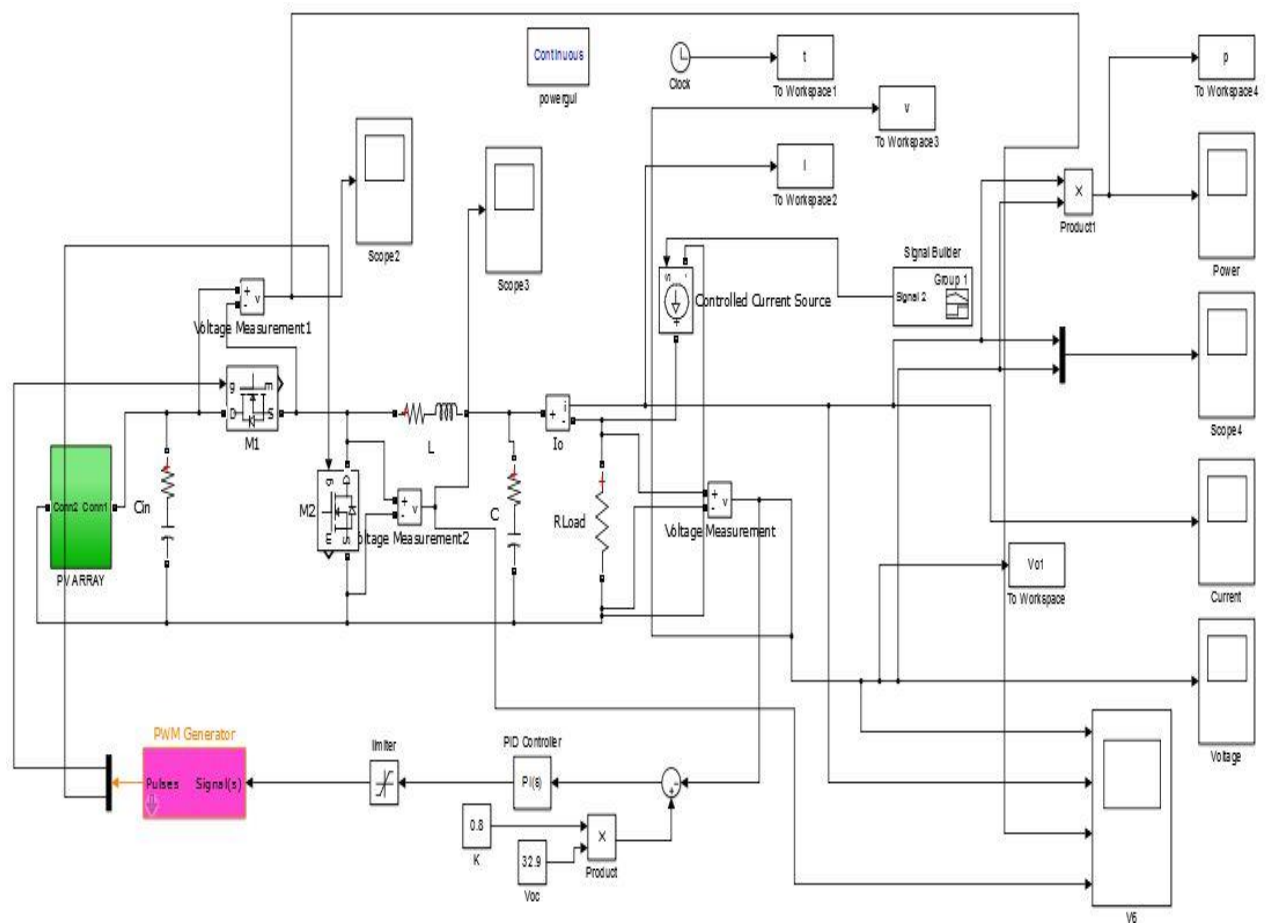


Figure 4.3 pv array interfacing of closed loop buck converter

SIMULATION RESULT

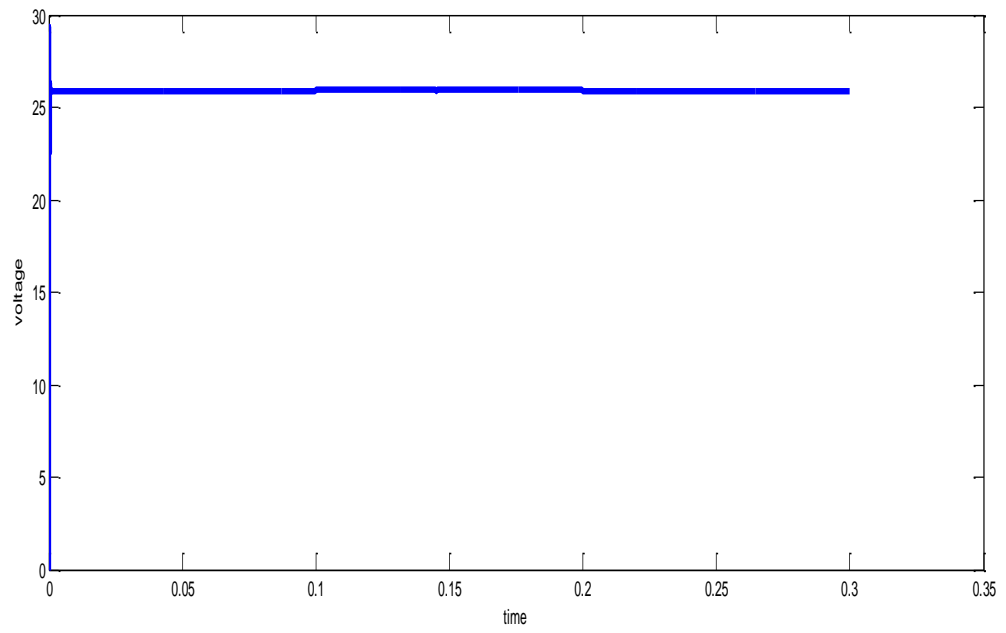


Fig- 4.4 output voltage

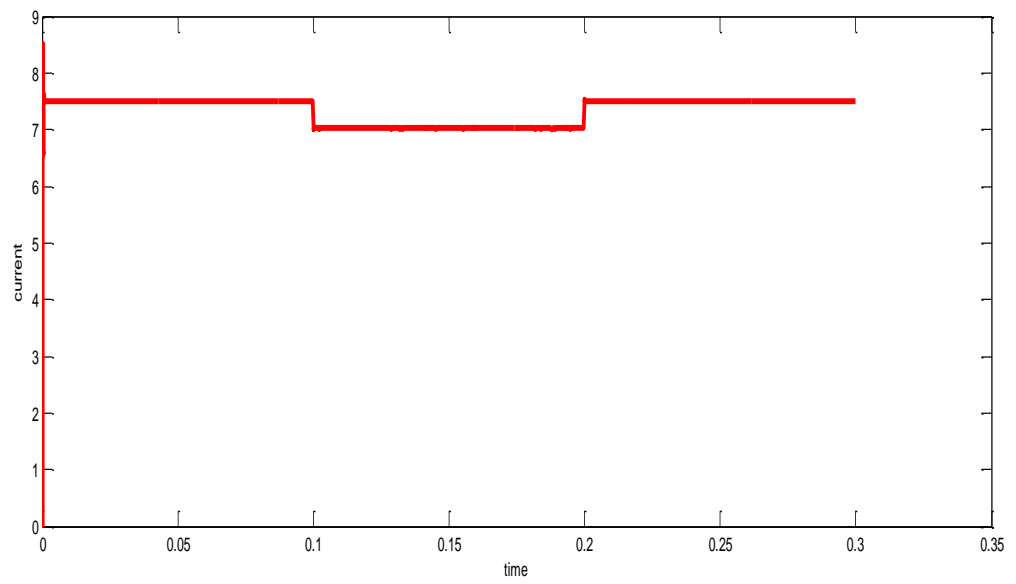


Fig-4.5 output current

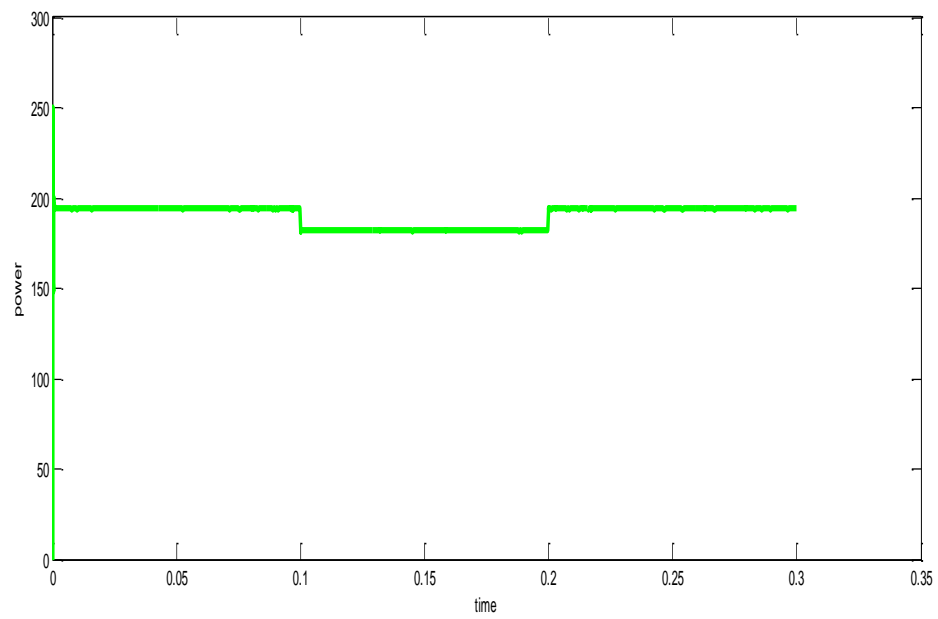


Fig-4.6 output power

CHAPTER 5

5.1. CONCLUSION

The project process simplified piecewise linear model for a PV array. In this work we have chosen the KC-200GT solar panel as the power source and simulated its I-V and P-V characteristics. The final simulation of PV-array along with MPPT and an impedance matching device. A synchronous buck converter was used to implement the MPPT algorithm because of its better efficiency in the fractional open-circuit voltage MPPT algorithm. The value of K was set to 0.75, as usually K varies between 0.7 & 0.8. A PI controller is used to precisely control the transient and study state response of the model under varying load as well as source variation. The MPPT algorithm used was fractional open circuit voltage algorithm,

Which is very Simple and can be implemented cheaply. In open loop simulation of synchronous buck converter there was significant error in the output value. This was due to the losses in the circuit elements and the inability of the system to compensate for it. Switching losses depend upon switching frequency chosen. In closed loop simulation the transient response, steady state error etc. depend on the proportional and integral constant values.

FUTURE WORK

- Study and simulation of advanced MPPT algorithms
- Hardware implementation of the set-up
- Simulation of effects of PI controller on transient response for different K_p and K_i values

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